

Deglaciation and drainage-pattern development in the eastern Uckermark, Brandenburg, Germany

Deglaziation und die Entwicklung der Entwässerungsbahnen im Osten der Uckermark, Brandenburg, Deutschland

Deglaciatie en drainage-patroon-ontwikkeling in de oostelijke Uckermark, Brandenburg, Duitsland

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Abstract

After retreat from the Angermünde Ice Margin, the Weichselian inland ice sheet fell apart into different independently acting ice tongues in the eastern Uckermark. In this region (bordering Poland), between the Angermünde and Penkun Ice Margins only the Schönermark Intermediate Ice Margin has been described before. This paper postulates two more ice margins: a Welse North Ice Margin and a Welse South Ice Margin. The Welse South Ice Margin is a ridge in the area northwest and south of the Welse stream (lower course) and can be followed over the villages Zehnebeck - Wendemark - Passow - Herrenhof - Berkholz. The Welse South Ice Margin is seen as a possible simultaneous continuation of the Zichow-Golm Ice Margin. Subglacial valleys developed, but unique drainage paths and sander at the Zichow-Golm Ice Margin and at the Welse South Ice Margin could not be found. In the area of Wartin - Schönnow - Kunow - Hohenfelde a distinct ridge can also be seen, here named Welse North Ice Margin. It is conceived as a possible simultaneous continuation of the Gerswalde Ice Margin. An exposure in the gravel pit south of Kunow shows exemplary the different push phases of the inland ice and periglacial phenomena in this area. The main meltwater direction was from north to south and between Wartin and Blumberg a sander terrace was formed at a level of 50 - 60 m above NHN in the Randow Valley.

Zusammenfassung

Nach Auflösung der Angermünder Eisrandlage kam es im Weichselspätglazial zu verschiedenen unabhängig voneinander wirkenden Gletscherzungen in der östlichen Uckermark. Zwischen der Angermünder Staffell und der Penkuner Staffell ist bisher nur der Schönermarker Zwischenstaffell beschrieben worden. In dieser Arbeit werden zwei weitere Eisrandlagen postuliert: eine Welsesüdrandlage und eine Welsenordrandlage. Die Welsesüdrandlage ist ein Höhenzug im Raum nordwestlich und südlich des Welse-Flusses und ist über die Orte Zehnebeck - Wendemark - Passow - Herrenhof - Berkholz zu verfolgen. Sie wird als eine Art (und möglich zeitgleiche) Fortsetzung der Zichow-Golmer Zwischenstaffell aufgefasst. Eindeutige Entwässerungsbahnen der Zichow-Golmer Zwischenstaffell und der Welsesüdrandlage konnten nicht gefunden werden. Im Raum Wartin - Schönnow - Kunow – Hohenfelde ist ebenfalls ein Höhenzug zu erkennen; die hier Welsenordrandlage genannt wird. Sie wird als eine Art (möglich zeitgleiche) Fortsetzung der Gerswalder Staffell aufgefasst. Ein Aufschluss in der Kiesgrube südlich von Kunow zeigt beispielhaft die verschiedenen Stauchungsphasen und Periglazialerscheinungen in diesem Bereich. Die wichtigste Schmelzwasserrichtung war von Nord nach Süd und zwischen Wartin und Blumberg wurde dabei in Höhe von 50–60 m NHN im Randowtal eine Sanderterrasse gebildet.

Introduction

A striking range of hills can be followed between Angermünde, Pinnow and Criewen. It was created at the end of the last ice age, the Weichselian, by pressure of land ice masses from the north and northeast, and was named by WOLDSTEDT (1925) the *Angermünde Ice Margin* (Figures 1 and 2).



Fig. 1: collective legend for Figures 2,3,4 and 9.

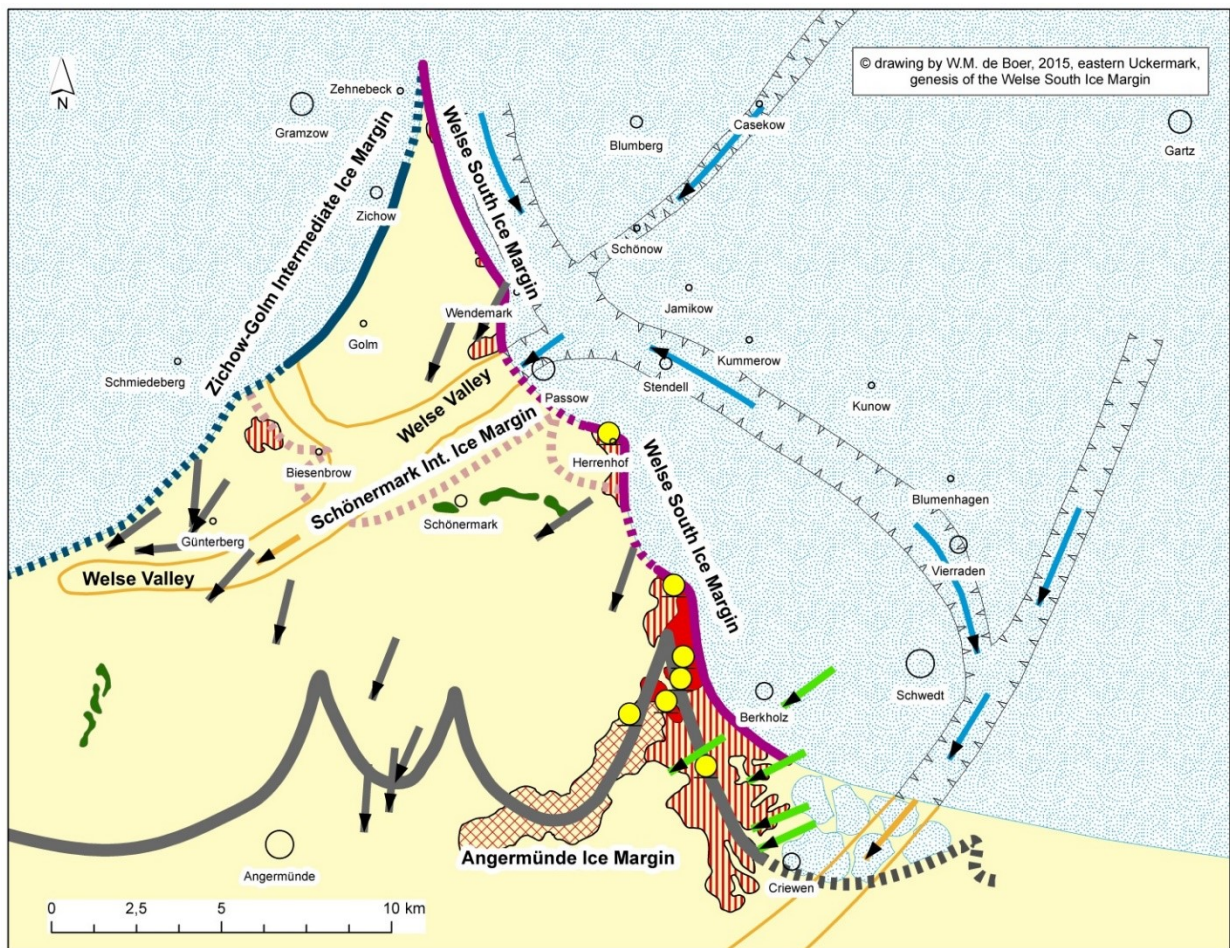
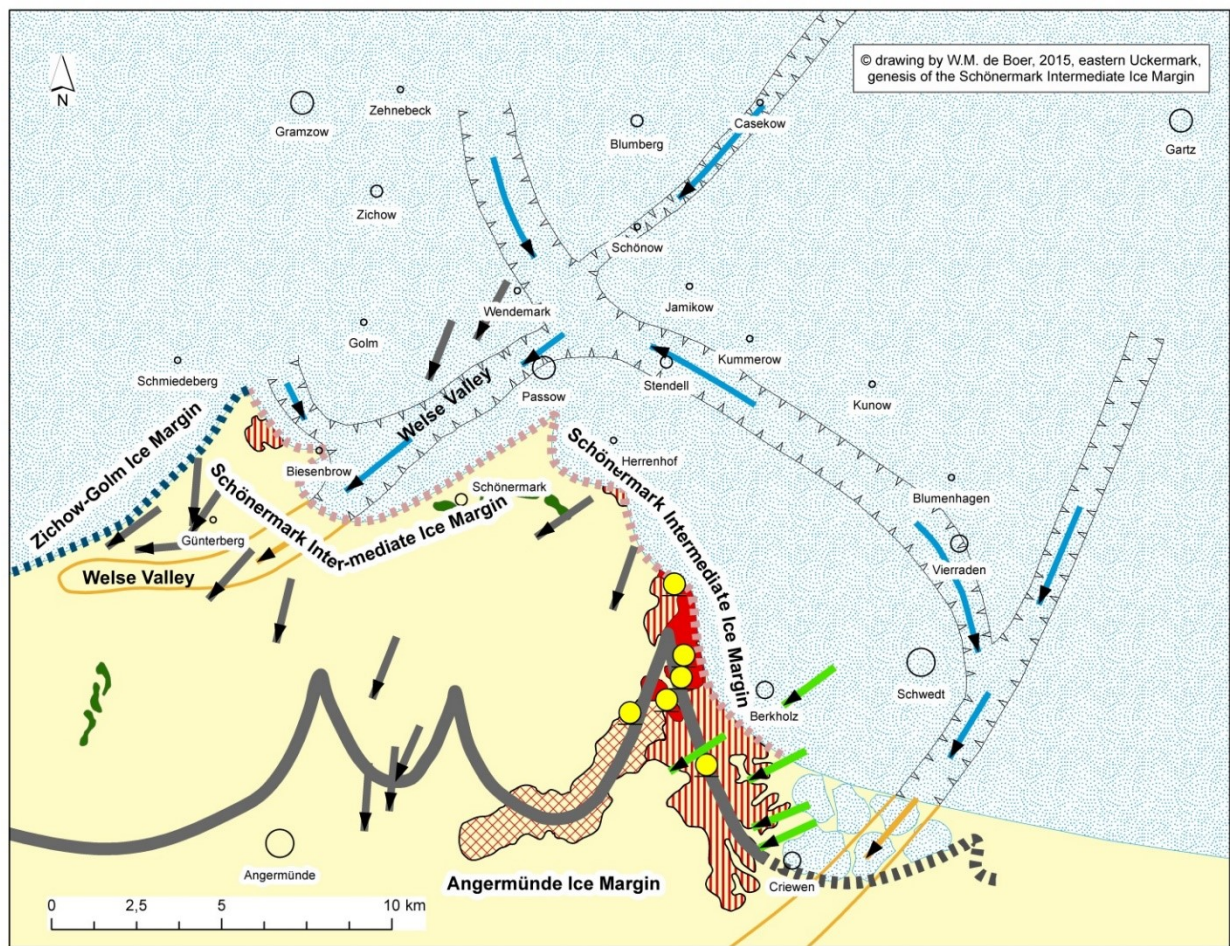
Abb. 1: Sammellegende für die Abbildungen 2,3,4 und 9.

Fig. 2: Sketch of the genesis of the Schönermark Intermediate Ice Margin (segment Biesenbrow-Schönermark after MICHAEL 1895 and 1899) with associated drainage paths, Weichselian push- and end moraines (locally with elements of older deposits) and in Weichselian times overridden Saalian push moraine complexes according to GÜK100. Green arrows indicate the by MAUDREI (1962) measured gravel long axes orientations and grey arrows the by BERGMANN (1964) measured gravel long axes orientations.

Abb. 2: Kartenskizze zur Entstehung der Schönermarker Zwischenstaffel (Abschnitt Biesenbrow-Schönermark nach MICHAEL 1895 und 1899) mit zugehörige Abflussbahnen, sowie weichselzeitliche (Stauch-)Endmoränen und (örtlich mit Schollen ältere Gesteine) und weichselzeitlich eisüberfahrene saalezeitliche Stauchungskomplexen nach GÜK100. Mit grüne Pfeilen sind die Geschiebelängsachseneinregelungen nach MAUDREI (1962) sowie mit graue Pfeilen die nach BERGMANN (1964) dargestellt.

Fig. 3: Sketch of the genesis of the Welse South Ice Margin with associated drainage paths, Weichselian push- and end moraines (locally with older elements of deposits) and in Weichselian times overridden Saalian push moraine complexes according to GÜK100. Green arrows indicate the by MAUDREI (1962) measured gravel long axes orientations and with gray arrows the by BERGMANN (1964) measured gravel long axes orientations.

Abb. 3: Kartenskizze zur Entstehung der Welsesüdrandlage mit zugehörige Abflussbahnen, sowie weichselzeitliche (Stauch-) Endmoränen und (örtlich mit Schollen ältere Gesteine) und weichselzeitlich eisüberfahrene saalezeitliche Stauchungskomplexen nach GÜK100. Mit grüne Pfeilen sind die Geschiebelängsachseneinregelungen nach MAUDREI (1962) sowie mit graue Pfeilen die nach BERGMANN (1964) dargestellt.



After retreat from the Angermünde Ice Margin, the Weichselian inland ice sheet fell apart into different independently acting ice lobes in the eastern Uckermark. From that time, the relief forming glaciation and deglaciation is no longer uniform throughout the basin of the whole Oderlobus but is clearly distinguished in individual sub-basins (CHROBOK ET AL. 1982). In the area of the Uckerseen three ice margins are known (CHROBOK ET AL. 1982) going from south to north: the Zichow-Golm Intermediate Ice Margin, the Gerswalde Ice Margin and the Ucker- or Penkun Ice Margin. The formation of these ice margins occurred in the period between 15,000 - 12,800 B.P. (DOMNICK & EBERT 1996) which is consistent with data from RINTERKNECHT ET AL. (2005) and HEINE ET AL. (2009). Opposed to this, LÜTHGENS AND BÖSE (2011) write: "*exposure ages suggest an ice-free surface north of the Pomeranian ice margin at least until the Gerswalde Ice Margin, already 17,000 years B.P. However, the exact course of the ice margin is still unclear*". Thus, in the eastern Uckermark (the area between Angermünde in the south, the Randow Valley in the west, Löcknitz in the north and the Oder Valley in the east) only the Schönermark Intermediate Ice Margin was described by MICHAEL (1895 and 1899). However, there are indications of the existence of two other ice margins: a Welse South Ice Margin and a Welse North Ice Margin.

Methods

In order to identify the possible existence of unknown ice-margins, preliminary cartographic work was carried out before the fieldwork began. Contour maps were made in the scales of 1: 25,000 and 1: 200,000. With the use of topographic maps 1: 25,000 („Messtischblätter“) ten transversal profiles - from north to south in the study area, at regular intervals - were drawn. With the use of the topographic maps 1: 25,000 a few longitudinal profiles with five times exaggeration were drawn (vertical scale: 1: 50,000 and horizontal scale 1: 200). Also, cross profiles of the Tantow-Schönow valley and the Salveybach valley were drawn. They allow a further interpretation of the contour maps in order to identify drainage patterns. In the years 1986-1991 pits were systematically searched, explored and placed on a topographic map. In most exposures, the strike and dip directions of the sedimentary layers were measured, the layers examined for material properties such as grain size distribution and composition, and sketches, dia negatives and photos were made. The pit Kunow was re-photographed and interpreted in the years 2012 and 2015. To test different genetic hypotheses of some peat, sand, gravel and till deposits and in addition to the geological maps 1: 25,000 some auguring was carried out with the 'Edelman Drill'. Detailed geomorphological and geogenetic maps of different studied subregions were drawn. The cartographic preparations were checked in the field and adjusted and expanded if necessary. In addition, in 2015 the results of the cartographic works were compared with the digital terrain model (DTM or DGM in german) with 1 m resolution (DGM1), thematic maps from literature sources like BERGMANN (1964) and recent geological and topographic maps of Brandenburg and Mecklenburg-Vorpommern.

Results

In the literature one intermediate ice margin between the Angermünde Ice Margin and the valley of the river Welse (lower course) is mentioned.

BERGMANN (1964, p. 21) writes: "R. MICHAEL (1895 and 1899) based on his geological mapping work, describes the „*Schönermark Intermediate Ice Margin*“. The Schönermark Intermediate Ice Margin is most clearly formed east and south of the village Schönermark. Through valley-like interruptions the intermediate ice margin is divided into several parts. The western part of the endmoraine extends from the Eich-mountains northwest of Schönermark towards Schönermark Station. In the Wein-mountain on the northern edge of the Welse valley R. MICHAEL (1895) hypothesises a continuation of the Schönermark Intermediate Ice Margin. The structure of the mostly 100 m wide terminal moraine is characterized by gravels, sands, coarse gravels and glacial till. At some points in the terminal moraine block packages („Blockpackungen“) occur. Behind the terminal moraine a basin has formed in which clays and sands have been deposited. Schönermark is located in the center of this small basin."

The by BERGMANN (1964) mentioned „Ice Margin 4“ does probably at least in parts overlap with the „Schönermark Intermediate Ice Margin“ by MICHAEL. BERGMANN (1964, p. 86) writes: "The most recent

advance in the study area [author's note: the study area of BERGMANN was 1964 northbound at the Welse / Randow valley] shall be referred to as 'Ice Margin 4'. The course of Ice Margin 4 can only be suspected at this moment. Fixed points of this latest ice sheet advance are the Langer-Berg (101.4 m) in Golm, the Schiefer Mountain (86.0 m) near Zichow and as 'Schönermark Intermediate Ice Margin' (MICHAEL 1895 and 1899) known end moraine complex south of the village Schönermark. R. MICHAEL already drew the 'Schönermark Intermediate Ice Margin' to the Wein-mountain near Biesenbrow. Even though the linking together of the heights of Ice Margin 4 is not very clear, the fact remains, that the terminal moraine of the Langer-mountain must be younger than the end moraines of the Ice Margin 3. The meltwater of ice margin 4 cut gutterlike breakthroughs into the terminal moraine of ice margin 3 between Felchow and Greiffenberg. One of these channels leads from Pinnow towards Dobberzin". Perhaps the Schönermark Intermediate Ice Margin is to be regarded as a kind of precursor or early phase of the Welse South Ice Margin.

On the modern Geological overview map 1: 100,000 (GÜK100) several eskers are drawn near Schönermark. So instead of a pushing and uplifting the authors of the GÜK100 more than 100 years after the publications of MICHAEL accept a quiet melting process in a dead ice field in the area of Schönermark. The western half of the by R. MICHAEL reported 'Schönermark Intermediate Ice Margin' is indeed drawn on the map of Fig. 2, but is therefore not without controversy, although on the GÜK100 pushed Weichselian deposits in the underground of the Wein Berg west of Biesenbrow were drawn (Fig. 2). Also, the by BERGMANN (1964) measured gravel long axes orientations in two exposures between Briest and Passow Station, that is in the back country of the Schönermark Intermediate Ice Margin, suggest an ice movement and pushing from NNE to SSW (Fig. 2).

The eastern half of the Schönermark Intermediate Ice Margin is drawn in Fig. 2 in such a way that the by BERGMANN (1964) drawn ridgelines are followed. The eskers from glacially calmer phases in the trajectory remain unaffected. In the eastern region of the Schönermark Intermediate Ice Margin this ridge borders the pushed Weichselian deposits area on the GÜK100 map (Fig. 2).

In the area south of the Randow- \ Welse-valley a distinct ridge is to be followed along the heights of the Eastern Zehnebecker Forest \ Eastern Zichower Forest - Räuber Mountains - Wendemark - heights west of Passow Station - south of Passow - Herrenhof - Blocksberg (northwest of Berkholz) and Hermann Berg (southwest of Berkholz) and is recognizable up to the Schlangen mountains southwest of Meyenburg (Fig. 3). This ridge is conceived as a continuation of the Zichow-Golm intermediate ice margin and may have been formed in the same cold phase during an advance of the inland ice. This ice margin is called by the author 'Welse South(ern) Ice Margin' (DE BOER 2015).

On the Geological Map 1: 100,000 (GÜK100) push moraines are drawn in several places in this area (units W2, e = Weichselian (push) moraines and w,, et = Weichselian (push) moraines, locally with elements of older deposits and sw,, et = in Weichselian times overridden Saalian push moraine complexes according to GÜK100, see Fig. 3). These deposits in Weichselian to Saalian push- and end moraines (locally with elements of older deposits) consist of sand, gravel, stones and / or glacial till, partly with ice transported deposits of Quaternary and \ or pre-Quaternary rocks and are more or less dislocated by ice pressure. Immediately north of Herrenhof and west of Berkholz material of Tertiary (Miocene and Oligocene) age was pressed upwards (see Figures 2 and 3). They constitute a proof of the pressure of land ice from a (east-) north-easterly direction. BERGMANN (1964) measured gravel long axes orientations as shown by arrows in Fig. 2 and in Fig. 3. They support the presumptive ice pressure directions from (east-) north-easterly direction. Beneath the ice subglacial valleys developed (Figures 2 and 3). The sander tracks in front of the ice front are indicated in the sketch maps with yellow lines and their drainage directions with yellow arrows. Sometimes parts of these deposits (mostly sand and gravel) are still to be found in the field at levels that are lower with increasing distance from the ice margin. Sometimes such sander deposits occur at different levels in the field and are then called sander terraces. At the same time, the outgoing meltwater could act erosively. The inner side of the Welse South Ice Margin has been eroded in this way partly by meltwater from subsequent deglaciation, e.g. that of the Welse North Ice Margin (see Fig. 4). This is why the Welse South Ice Margin cannot be pursued without gaps. The outside of the Welse South Ice Margin does not have or only has weakly developed sander. Unique drainage paths of the Zichow-Golm Ice Margin could also not or could hardly be found (MARKUSE 1969). The meltwater of the Welse South Ice Margin and the Zichow-Golm Intermediate Ice Margin may have been trapped (backwater) in the area south of Günterberg-Biesenbrow

because of presence of dead ice in the Welse Valley (lower course). When stowing the meltwater fine sediments were deposited in the calm waters in the form of varved clays (so-called 'Bändertone', MARKUSE 1969).

A second clear ridge is to be traced east of the Randow Valley and north of the Welse river (lower course) along the places \ heights Wartin (Eckernberge) - Blumberg (Hexenberg) - Schönnow (Bauernheide) - Eichberg - Galgenberg near Jamikow (in the Nature Reserve Area NSG 'Trockenrasen Jamikow') - Kummerow - Müllerberge (in the NSG Müllerberge, south of Kunow and Hohenfelde), recognizable both in the field and on the digital terrain model (DTM) of the Brandenburgviewer, on the old topographic maps (Messtischblätter) and on the landscape visualization of J. KIESEL (in LEHRKAMP 2015). It projects up south of Schönnow by more than 62 m and south of Kunow-Hohenfelde to more than 55 m above the Welsetal and is called by the author Welse North Ice Margin or shortly Welse North Margin (Fig. 4).

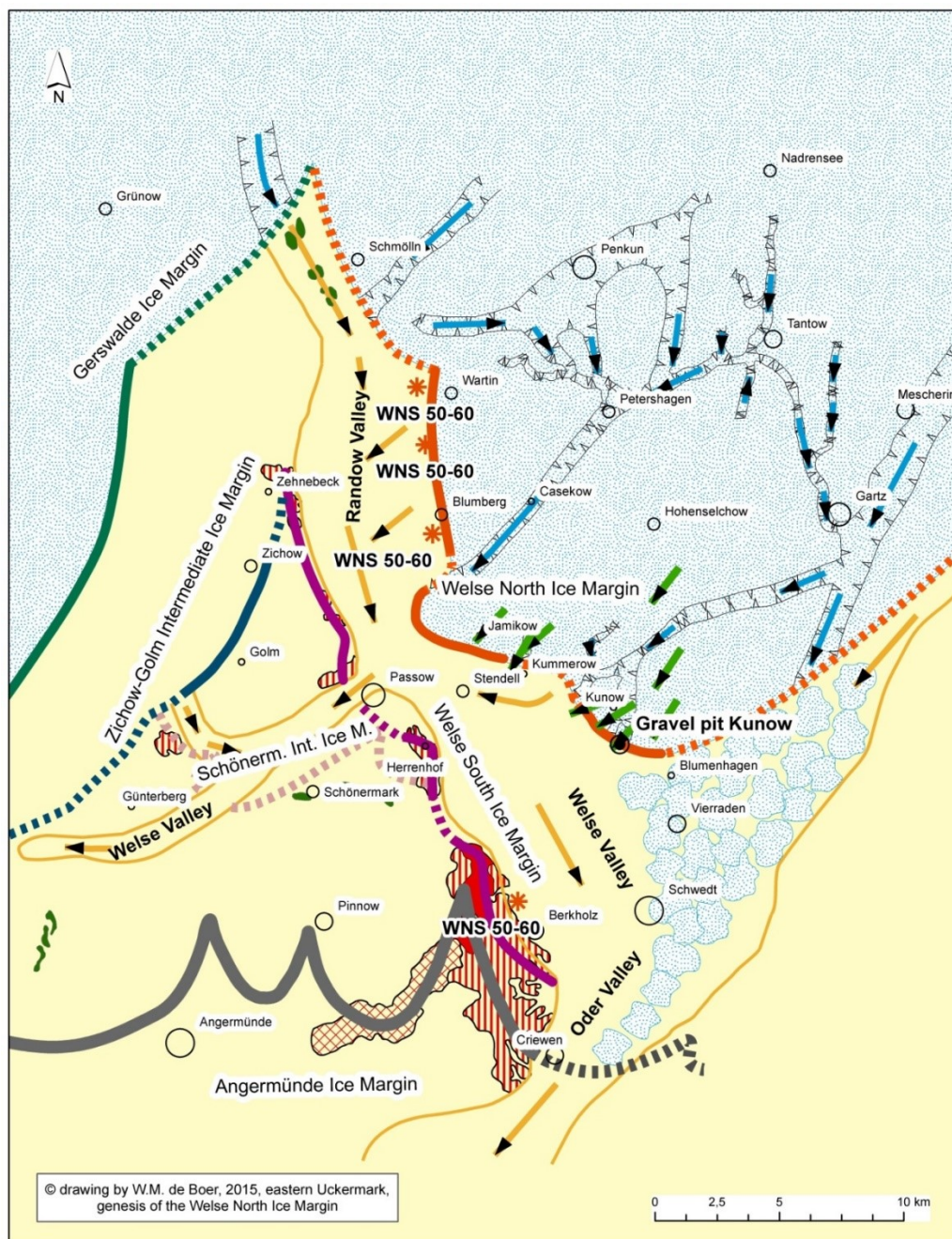


Fig. 4: Sketch of the genesis of the Welse North Ice Margin with associated drainage paths. Dark green arrows indicate the by MAUDREI (1962) measured gravel long axes orientations drawn.

Abb. 4: Kartenskizze zur Entstehung der Welsenordrandlage mit zugehörige Abflussbahnen. Mit dunkelgrüne Pfeilen sind die Geschiebelängsachseineinregelungen nach MAUDREI (1962) dargestellt.

In the field, there are the following additional observations which support the adoption of this Welse North Margin:

- 1) The ridges between Wartin and Schönow (west and southwest section of the Welse North Margin) are better built (namely higher) than between Schönow and Hohenfelde (southern and south-eastern section of the Welse North Margin). This observation is consistent with those of Markuse (1969) in the area of the Uckerseen where the western compression zones are better built and are better trackable than the eastern ones (pressure from the ice edge more west than east).
- 2) Approximately 500 m northwest of Kummerow (old track to Jamikow) was observed on the hill side, that in about 32 meters above NHN the gravel surface submerged to the north under the boulder clay or glacial till, that is: the till was pushed on to the gravel from the north with a slight dip to the north (see Fig. 3 in de Boer 2015).
- 3) In a gravel pit profile in the nature reserve Müllerberge, south of Kunow, between the Birkenweg and Müllerberge (middle of the profile: WGS: 14.26134, 53.12468, see also: <https://www.google.de/maps/@53.12468,14.26134,17z> EPSG 25833 Brandenburg: 450571.84821, 5886394.84285) clearly recognizable compressed (deformed) layers were observed that indicate a pressure direction of N(N)E (see Figures 5-8). The gravel pit is located on the eastern edge of a dry valley, which is about 400 meters long and extends from the dirt road heading north passing by the hill with a height of 49.4 m NHN. The stages of development of the Welse North Margin can be illustrated by describing the structure of this exposure as follows.

Exegesis of the layers in Figures 5-8:

1-2: Podsol (where 1a = humus layer, 1b = bleached horizon - Ae 2 = Sesquioxide enrichment horizon - Bhs), 3 = Spodo-dystric cambisol (Podzol brown soil), 4 = glacial till (compressed) \ Till (deformed), 5 = gravels and sands (deformed), 6 = fine to coarse gravel (banded), 7 = till (pushed \ deformed), 8 = fine sand (FS) to very fine sand \ VFS), 9 = fine- to coarse gravel (banded), 10 = fine gravel to coarse gravel (in bands but otherwise unsorted), 11 = Fine sand (FS) 12 = (loamy) Till, 13 = Till, 14 = Till (probably more calcareous), 15 = Till (with cryoturbation influences) and without a number: breakdowns (Versturz), shown as grey shading in a white field (only in Fig. 8).

To the right (beginning at the text “50m”) in Figures 5-8 the break of slope (‘Hangknick’) to the Welse valley (lower course) can be seen. Several meters of till layers are located down in the profile (layers Nr. 15, 14 and 13). Possibly remnants of dead ice blocks of previous ice advances were present beneath those till layers. This is a likely interpretation since the Welse valley, an ice marginal valley, directly borders the profile in the southern part of the gravel pit (in the drawing to the right). In addition, the gravel pit is located in a periglacially formed valley (dry valley) that probably already developed subglacially. In the southern part of the gravel pit layer 15 moreover shows cryoturbation structures (see Fig. 5). On top of these tills alternating layers of sand and \ or gravel were deposited due to fluvio-glacial processes (Fig. 5, Nos. 12, 11, 10, 9, 8 and 7). The embankment direction of layer 12 could not be established, so that both an embankment from a northern direction (as drawn) or from other directions is possible. It might here therefore also be the so-called 20-meter terrace in the sense of KLOSTERMANN (1968), if an embankment direction from the east would be accepted for this ice marginal valley level. Layer 8 has a large very fine sand component and can also contain an aeolian component.

In a subsequent colder phase, by the pressure of the ice advance (weight pressure from above and laterally from a NNE direction), the already deposited layers - probably in a frozen state - were tilted (see Fig. 6). The subsequent melt out of dead ice remnants in the underground caused a ‘rotational slump’ of the layers in the southern half of the gravel pit (see Fig. 7). The presumptive sliding along a concave-upward slip surface is marked by a dotted red line and the direction of the sliding by a red arrow.

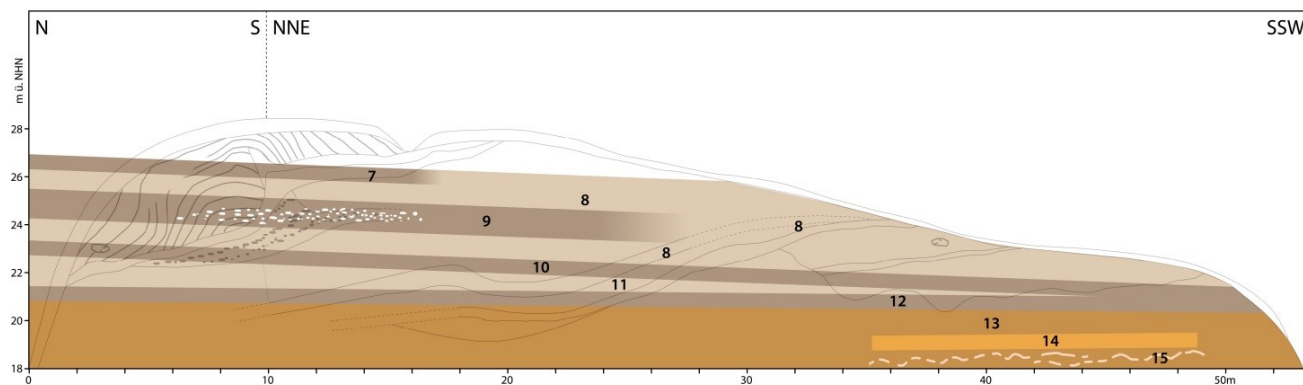


Fig. 5: Phase 1 of the genesis: geological profile of the gravel pit Kunow: deposition of alternating glacial and glaciofluvial deposits. Colored deposits (colors reflect colors observed in the field) are described in the text and the background in grey represents the present situation.

Abb. 5: Phase 1 der Entstehung: geologisches Profil der Kiesgrube Kunow: Ablagerung von einander abwechselnden glaziale und glaziofluviale Schichten. Farbige (Farben ähneln die wahrgenommenen Farben im Gelände) die im Text beschriebenen Ablagerungen und als Hintergrund in Grau die heutige Situation.

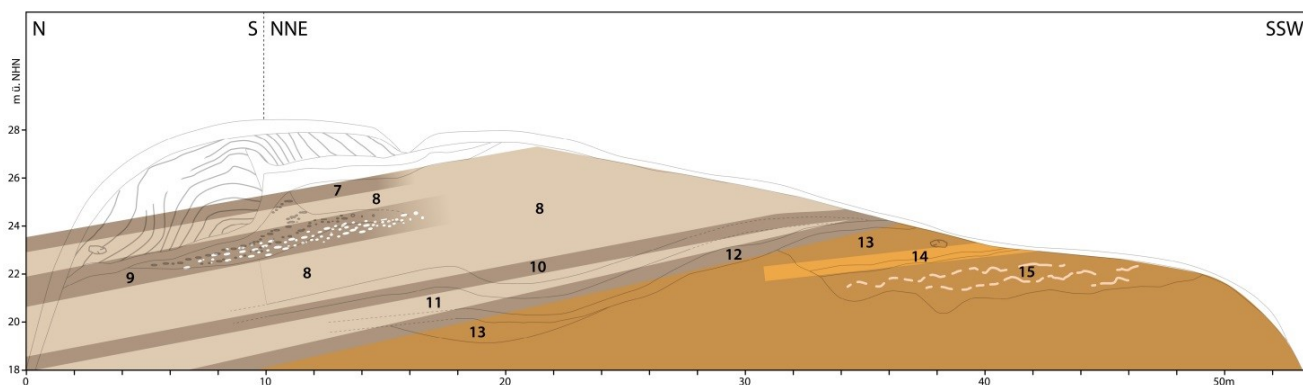


Fig. 6: Phase 2 of genesis: glacial tectonic tilt of the deep-frozen layers in the gravel pit Kunow.

Abb. 6: Phase 2 der Entstehung: glazitektonische Schiefstellung der tiefgefrorenen Schichten in der Kiesgrube Kunow.

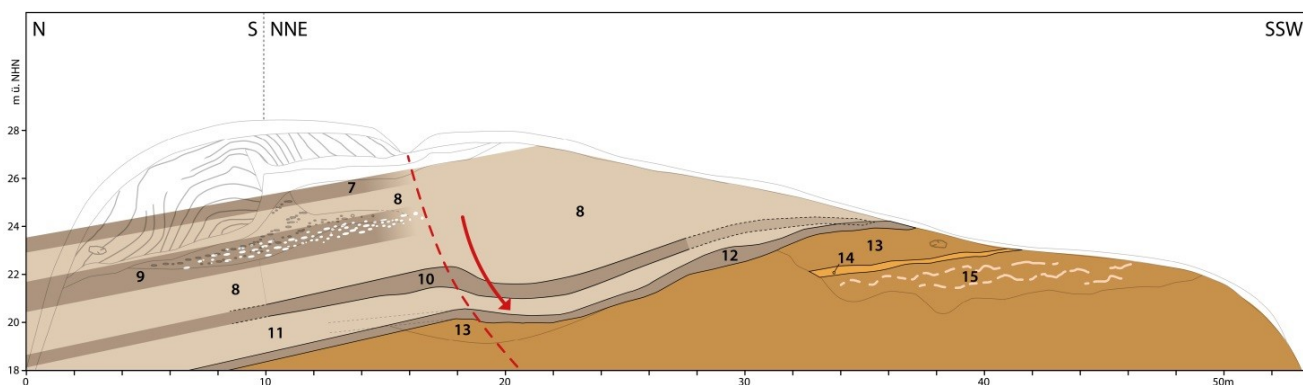


Fig. 7: Phase 3 of genesis: Rotational slump by the probable melting of dead ice remnants in the underground and/or in the Welse Valley (to the right in the drawing).

Abb. 7: Phase 3 der Entstehung: ‚Rotational slump‘ durch das vermutliche Abschmelzen von Toteisreste im Untergrund und/oder im Welsetal (in der Zeichnung an der rechten Seite).

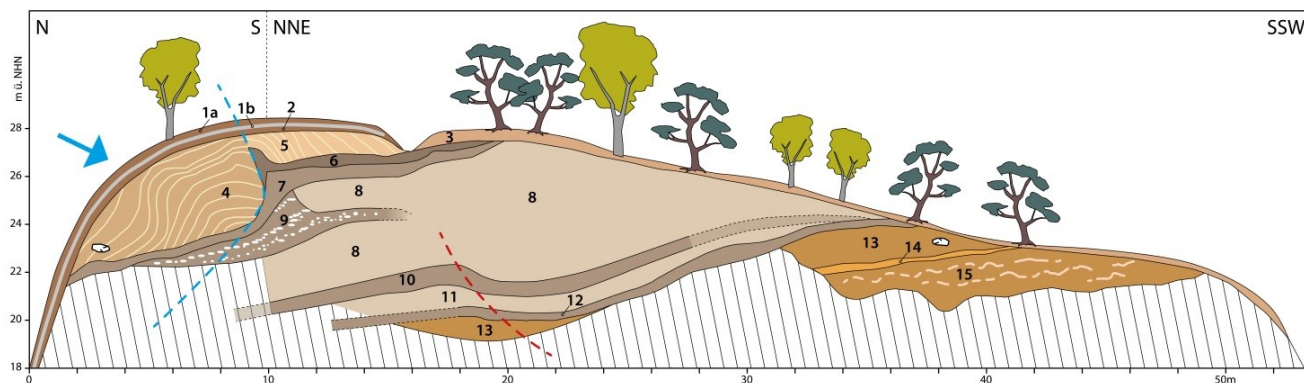


Fig. 8: Phase 4 of genesis: deposition of a till (layer 6) and gravels and sands under relatively calm conditions. Then pressure of till from the north (layer 4). This caused stowage and bending of the layers in the northern part of the gravel pit and a displacement of the layers 6 and 7 over the underlying layer of sands, layer 8.

Abb. 8: Phase 4 der Entstehung: Ablagerung eines Geschiebelehm (Schicht 6) und Kiese und Sande unter relativ ruhigen Bedingungen. Danach Aufpressung von Geschiebelehm aus dem Norden (Schicht 4). Dadurch Stauung und Biegen der Schichten im Nordteil der Kiesgrube und ein Auffahren der Schichten 6 und 7 über den unterliegenden Sanden der Schicht 8.

In a subsequent relatively 'quiet' phase again a till layer (layer no. 6) is deposited under the land ice (see Fig. 8). In addition, subsequently gravels and sands (layer no. 5) are deposited in front of the ice. By a final advance of the inland ice - shown with a blue arrow in Figure 8 - in the northern part of the gravel pit already existing layers (no. 9, 8, 7, 6 and 5) were compressed and one last till package (no. 4) was deposited. The package of no. 4 collided with already existing layers, the blue dotted line represents the assumed collision front (see Fig. 8). The layers 4 and 5 display in themselves clear arcuate folds, whereby the fresh exposure in the summer of the year 1987 showed the folds much better than the present exposure of weathered surfaces does. When the layer 4 collided against the layers 6, 7 and 9, they were also deformed and moreover the layers 6 and 7 also pushed over the package of the sand layer 8 to the south. The land ice however did not affect deeper layers such as layer 10. In summary, from Figures 5-8 can be extracted that clearly recognizable folded layers terminate the genesis of the stratigraphy forming process, which point to a pressure direction of the latest Vistula ice in this area from N(N)E. As an additional argument, the results of the long axes orientation measurements after MAUDREI (1962) can be used. His results are shown with dark green arrows in Fig. 4 and support the presumptive ice push from north-(north-)easterly direction. The Müllerberge gravel pit substantiates that this is a terminal moraine with evidence of ice pressure deformation. The old geological map 1: 25,000 (Geologisches Messtischblatt Cunow, 1899) shows in this area only the legend unit 'Upper Till' ('Oberer Diluvialmergel', that is, 'Geschiebemergel'). To the north of and above the exposure on the Geological MTB the unit 'Upper Sand' ('Obere Sand') and in the deeper parts of the exposure, the unit 'Lower Sand' ('Untere Sand', that is: 'under the first till') is mapped. This endmoraine is so far not registered in the modern Geological map 1: 100,000 (GÜK100).

In conclusion, in the future the area of the gravel pit Kunow should be mapped as 'Weichselian (push) moraines' ('weichselzeitliche (Stauch-)Endmoränen'), on the GÜK100 legend Unit w2,,e. This is probably also the case in a lot more areas of the Welse North Ice Margin. The example of the exposure about 500 meters northwest of Kummerow has already been mentioned. To what extent the Welse North Ice Margin is to be tracked to the north and west of Wartin is unclear. From the map in Fig. 4 it becomes clear that there has been a connection via Schmölln to the Gerswalde Ice Margin. In this period, the Oder valley and the Schönnow-Tantow valley were formed already as so-called subglacial valleys as a result of pressurized meltwater under the ice (Fig. 4). After the Welse North Ice Margin was abandoned, these valleys functioned as meltwater channels, i.e. as sander tracks of the next halt of the glacier tongue (Penkun Ice Margin). The main flow direction of the meltwater was from north to south. Between Wartin and Blumberg a sander terrace was formed in the Randow valley at the height of 50 - 60 m NHN (Fig. 4, indicated in the map with: 'WNS 50-60'). This sander connects to the north at the Penkun Ice Margin, but cannot be pursued south of Blumberg towards Schönnow and Stendell. Remains of this sander are found only again immediately north of Berkholz (where the 'Mineralölverbundleitung complex Schwedt' was built). Probably the meltwater

flowed toward Günterberg where varved clays („Bändertone“) could form again. Possibly remnants of the sander in the lower Welse valley have been eroded by the subsequent Randow braided river („Urstrom“). When the ice in the back country of the Welse North Ice Margin melted, a big dead ice remnant remained in the area of the Oder River for a long time. At its edges kames terraces formed which show melt-out features such as subsidence forms.

In the Penkun area the ice margin is divided into two parts: a slightly older *Penkun South Ice Margin* and a slightly younger *Penkun North Ice Margin* (Fig. 9). The scenery of the Penkun Ice Margin shows that the northern slopes and the southern slopes of the ice margin parts are relatively steep. In a first advance of the inland ice the heights of the Penkun South Ice Margin starting from the Black Mountains, south of Grünz over the area south of Sommersdorf - Penkun - north Büssow - south Storkow - Nadrensee were formed and the relief in this area was greatly increased.

During a second advance, the Penkun North Ice Margin was formed. At that time in front of the active, continuous inland ice sheet - probably in already existing valleys under the ice sheet -, at several places so-called dead ice blocks („Toteisblöcke“) remained that were covered by sands and gravels during a subsequent melt-out phase. During the melting of these dead ice remnants a more or less wide depression zone could develop, especially between the Penkun South Ice Margin and the Penkun North Ice Margin parallel to the terminal moraine. This depressed zone consists of deep basins, several of which are filled with water. At the third advance this process was repeated, but much less pronounced. After the pushing of the Penkun Ice Margins, according to DOMNICK AND EBERT (1996) after about 12,800 years ago, meltwaters accumulated in the Penkun area, and a kind of terraced surfaces were formed. The (southern) Penkun Ice Margin was then broken through after a certain time by meltwaters and in the vicinity of Kirchenfeld, Büssow (both adjacent to eskers), Radekow and Rosow. An ‘esker’ or ‘os’ is a narrow, elongated, often curved, embankment or similar wall-like mound of meltwater sands and -gravels of differing height, which was formed during an Ice Age under the glacier. In this way, in addition to relative flat and wide areas, eskers (‘Oser’ or ‘Oszüge’) have been formed in the area south of Penkun. This suggests a quiet and slow melting process until the pushing of the Rosenthal Ice Margin. Some of the meltwaters may have exploited already existing subglacial valleys. In this way sander terraces with heights of 36 - 40 m NHN were formed. The meltwater that flowed away in a southerly direction over the Schönow-Tantow Valley at a height of 36 - 37 m NHN is likely to have contributed to the formation of local varved clays (so-called ‘Bändertone’), in many small spots, particularly in the Schönow-Tantow Valley and near Günterberg (Günterberg varved clays or ‘Günterberger Bändertone’). A portion of the meltwater of the Penkun Ice Margin drained away over Rosow - Geesow - Gartz and possibly also over Radekow - Tantow - Gartz. To the west the Penkun Ice Margin (southern part) probably borders to the Gerswalde Ice Margin and to the Ucker Ice Margin (Fig. 9).

The northern part of the Penkun Ice Margin can be traced to the west up to the Ucker push zone from Sommersdorf on to Grünz, Schmölln, Schwaneberg and Wallmow. A parallelization of these two phases however is difficult. Both parts (north and south) of the Penkun end moraine, both east and west of the Randow, contain chalk elements. This leads to the conclusion that both parts have a similar and simultaneous formation. Heights such as the Tuleier Berge at Luckow near Sommersdorf and east of Ladenthin, probably originating from the Saalian, were presumably nunataks surrounded by the Vistula ice. After ablation of the Penkun Ice Margin(s) it came to the formation of the Rosenthal Ice Margin. Sander tracks of this vigorously formed Ice Margin built terraces in the eastern Uckermark at a height of 28 - 22 meter NHN (usually 24 - 23 m NHN), which occur with a southern gradient in the Randow valley, in the Schönow-Tantow valley and in the valley of the Salvey brook. In the area of Blumberg however, this terrace level could only be detected in a narrow strip. Deposits of this sander likely further raised the varved clays deposits in the Schönow-Tantow valley and near Günterberg. The at the time of the Penkun Ice Margin existing Schmölln-Grünz glacier mouth formed an only slightly enlarged section of the Randow valley during the existence of the Rosenthal Ice Margin.

After ablation of the Rosenthal Ice Margin the meltwater could flow away over the braided river network of the Netze-Randow-glacial valley to the north. Four terrace levels were created by erosion in four different phases (KLOSTERMANN 1968). South of Kummerow and between Passow and Schwedt, DE BOER (2015) found proof for the existence of the Bagemühl Terrace (‘Level 4’ after KLOSTERMANN 1968) for the first time.

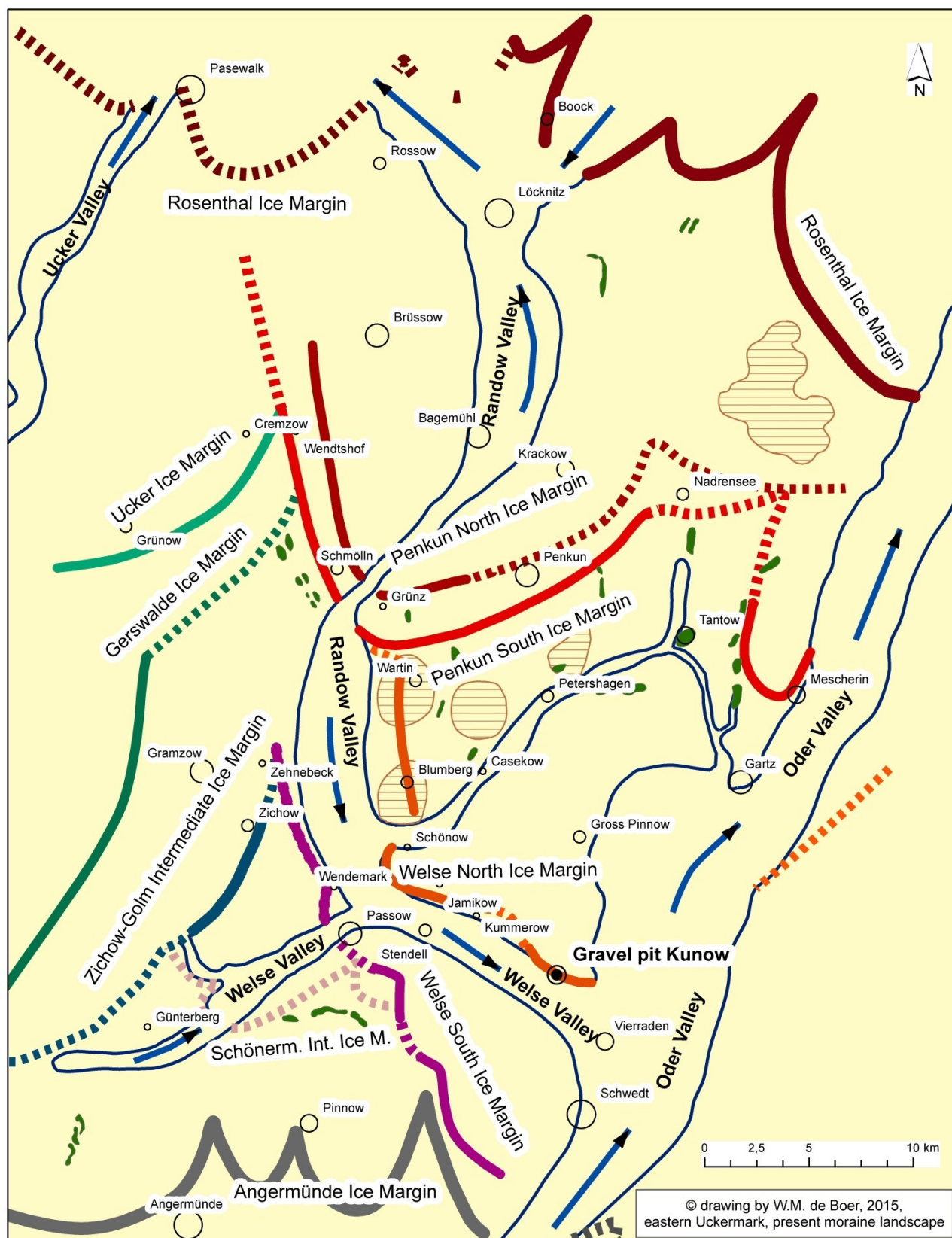


Fig. 9: Today's moraine landscape of the eastern Uckermark.
Abb. 9: Heutige Glaziallandschaft der östlichen Uckermark.

Table 1: Terraces in the Randow valley after KLOSTERMANN (1968) and DE BOER (2015).**Tabelle 1:** Terrassen im Randowtal nach KLOSTERMANN (1968) und DE BOER (2015).

Terrace level after KLOSTERMANN (1968)	description:	Height of the terrace in m NHN near:			
		Bagemühl	Blumberg	Stendell	Schwedt
4	Bagemühl Terrace	16.5-21.5	18-22	not formed	20 (DE BOER 2015)
3	Meyenburg Terrace	13-16	14-17	16-17	13-17
2	Stendell Terrace	9.5-12	10-12	12-13	10-11
1	Schwedt Terrace	6-7	7.5	8-9.5	6-8

Table 1 shows the by KLOSTERMANN (1968) mapped terraces in the Randow / Welse valley in a four-stage system. KLOSTERMANN (1968) writes the following about this scheme: "From the overview it can be deduced that four terrace levels are formed with a north gradient in the Randow valley."

The numbers 1-4 unite the levels found in many places, the highest (oldest) levels receive the number "4", and the lowest (youngest) the number "1". As a result of the gradient occur in different levels, the names listed are derived therefrom. MARCINEK (1969) assumes that at Vierraden-Schwedt the fourth terrace occurs at an altitude of about 20 m NHN. This theory is supported by DE BOER (2015). The Stendell Terrace (Level 2) near Schwedt is also called the "bifurcation terrace", since it is virtually divided into two parts. On this terrace the Petroleum Factory Schwedt ('Erdölverarbeitungswerk Schwedt'), the current PCK Raffinerie GmbH, was built in 1958. With further ice retreat the area of the so-called "Haffstausee" (a lagoon like reservoir), where the meltwater poured in, grew larger and the erosion base lowered (BRAMER 1964). BRAMER has extended the three by earlier workers recognized Haffstausee terraces to ten, which are located between +30 m and -6 m NHN. The uppermost deposits in 30 m NHN probably belong to an independent reservoir, but from 20 m NHN on, the braided Netze-Randow- system has poured into the basin of the Haffstausee and the outflow was located in a northwesterly direction (JANKE & REINHARD 1968). At the same time the channel of the Salvey brook did not manage to drain the waters over Nadrensee northward. Near Tantow the waters began to flow toward the southwest through the Tantow-Schönow valley in the Blumberg section ('Blumberger Talweitung') of the Randow valley. Patches build of sandy deposits in the Tantow-Schönow Valley are located at an altitude of 20 - 23 m NHN and tilt toward the Randowtal.

In the periglacial environment following the Weichselian Ice Age the sands in the eastern part were partly dispelled because the Salvey Valley became a tributary to the river Oder, but the western part remained as a dry valley (KLOSTERMANN 1968). The final event in the runoff through the Randow Valley is characterized by an erosional cutting in several phases, corresponding to the over the entire length traceable four terraces. Erosion and accumulation intervened strongly with each other and went along with the lowering of the erosion basis (KLOSTERMANN 1968).

Towards the end of the Vistulian Late Glacial the Randow Valley will have fallen dry due to the decreasing water volumes while the waters in the Oder Valley could still erode. From this period stem the following Oder terraces: the in the study area youngest O1-level (DE BOER 2015) lies between 1.25 - 2.5 m NHN and the in the study area oldest O2-terrace level (DE BOER 2015) lies between 2.5 - 5 m NHN. Thus, again the gradient was reversed, which finally broke the continuous flow (BRAMER 1964). The southern Randow Valley, in combination with the Welse Valley discharched from now on to the Oder, the northern catchment area however, beginning at Schwaneberg, discharched to the Ucker river (KLOSTERMANN 1968). Further melting of the inland ice caused gully formation by retrogressive erosion in the Randow Valley and in the Oder Valley. By means of material removal the Randow and Oder cut constantly further into the underground in source direction. At that time, the Baltic coast lay much further north than at present. The Netze-, Randow- and Oder-glacial valleys fell dry.

In the Oder Valley and partially also in the Randow \ Welse Valley terrace sand drifts developed at this time. In this way, inland dunes were formed in the area east of Groß-Pinnow. The sand drifts in the Randow \ Welse valley are smaller scaled than the ones in the Oder Valley and largely covered in the Holocene by peat. Only occasionally do the crests of the dunes there reach the surface.

In the Holocene, the water levels of the Baltic Sea rose and caused a rise of the groundwater levels in the Uckermark. This in return caused a strong peat- and moor formation in the Randow Valley. Peat in the former glacial valleys and their side valleys was mostly not mined (LEHRKAMP 2015).

In the area between Jamikow and Kummerow on the border of the meadows of the Welse river at a height of 10 - 12 m above NHN at regular intervals before the dents of the valley incisions clearly recognizable alluvial fans are located. The transition to the steep edge is marked by a distinct break of slope. The colluvial heightening north of the unpaved road is situated well above the level south of the road, which suggests a colluvial cover of about 1.5 - 2 m. Alluvial formations such as after the strong thunderstorms on the 20th of July 1987 of 10 to 15 cm thickness support this assumption.

The anthropogenic influences in the Eastern Uckermark are mostly of agricultural- and water management-nature. The infrastructure shows relatively little impact on the landscape. Noteworthy are the Berlin - Penkun - Szczecin motorway, the railway line Angermünde - Tantow and the railway line Angermünde - Schwedt, as well as the Hohensaaten waterway and the Landgraben and the vast areas of the PCK Raffinerie GmbH west of Schwedt/Oder.

Many dead ice kettles were used as livestock waterings, 'Rötplätze' (used for flax processing) or fire extinguishing ponds. Field borders ('Ackerrandstufen', or 'Hochraine') were used as landmarks and as 'stone trash heaps'. They often point to glacial till because they remain erect in a natural way during ploughing.

A further deepening and detailing in the research on the history of the former ice borders and their drainage pattern remains desirable. Modern research methods such as the analysis of laser scan data and 3D landscape models - such as described by DALCHOW, KIESEL & LUTZE (2012) - with the help of Geographic Information Systems (GIS) and Remote Sensing software provide new opportunities. Ground-Penetrating Radar (GPR) is also a promising method for analysing geological structures in the recently discovered Ice Marginal Zones, such as the Welse South Ice Margin and the Welse North Ice Margin.

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This study is basically the result of a study (1986-1987) at the Humboldt University Berlin when I was still studying Physical Geography at the University of Utrecht (Netherlands) and also later mapping work with the help of Geographic Information Systems (GIS).

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Summary (Erweiterte Zusammenfassung)

After retreat from the Angermünde Ice Margin, the Weichselian inland ice sheet fell apart into different independently acting ice tongues in the eastern Uckermark. In the area of the Ucker lakes three ice margins are known: going from south to north: the Zichow-Golm Intermediate Ice Margin, the Gerswalde Ice Margin and the Ucker Ice Margin. In the eastern Uckermark (bordering Poland) however, between the Angermünde Ice Margin and the Penkun Ice Margin only the Schönermark Intermediate Ice Margin has been described before. Two more ice margins are postulated: a Welse North Ice Margin and a Welse South Ice Margin. The Welse South Ice Margin is seen as a kind of (and possibly simultaneous) continuation of the Zichow-Golm Ice Margin. On the Geological Map 1: 100,000 push moraines have been registered in several places in this area. They constitute a proof of the pressure of the ice from the (East-)Northeast. Beneath the ice subglacial valleys developed. Unique drainage paths and sander of the Zichow-Golm Ice Margin and of the Welse South Ice Margin could not be found. The meltwater of these ice margins on the other hand formed so-called 'Bändertone' (thinly laminated clays or varved clays) in the area south of Günterberg-Biesenbrow.

In the area of Wartin - Schönow - Kunow - Hohenfelde a distinct ridge can also be seen; the so-called Welse North Ice Margin. It is conceived as a kind of (possibly simultaneous) continuation of the Gerswalde Ice Margin. The following supporting field observations were made: the ridges between Wartin and Schönow are better formed (i.e. higher) than those between Schönow and Hohenfelde, consistent with the observations of MARKUSE (1969) in the area of the Ucker lakes where the most western compression zones are better formed and trackable than the eastern zones (pressure from the ice front more west than east). Furthermore, pushed layers were observed in an exposure south of Kunow which suggest a pressing direction of N(N)E. On the slope of the valley, approximately 500 m northwest of Kummerow it was observed that the glacial till was pushed from the north on the gravel with a slight dip to the north at about 32 m height above NHN. The meltwater direction was from north to south and between Wartin and Blumberg a sander terrace was formed here at a level of 50-60 m above NHN in the Randow Valley. Probably the meltwater flowed toward Günterberg where Bändertone were formed again. The Oder Valley and the Schönow-Tantow Valley were formed already at that time as subglacial valleys.

Erweiterte Zusammenfassung (Summary)

Nach Auflösung der Angermünder Eisrandlage kam es im Weichselspätglazial zu verschiedenen unabhängig voneinander wirkenden Gletscherzungen in der östlichen Uckermark. Im Bereich der Uckerseen sind drei Eisrandlagen bekannt und zwar von Süd nach Nord: die Zichow-Golmer Zwischenstaffel, die Gerswalder Staffel und die Uckerstaffel. In der östlichen Uckermark dagegen ist bisher zwischen der Angermünder Staffel und der Penkuner Staffel nur der Schönermarker Zwischenstaffel beschrieben worden. Zwei weitere Eisrandlagen werden postuliert: eine Welsesüdrandlage und eine Welsenordrandlage. Die Welsesüdrandlage wird als eine Art (und möglich zeitgleiche) Fortsetzung der Zichow-Golmer Zwischenstaffel aufgefasst. Auf der Geologische Übersichtskarte 1: 100.000 sind an mehreren Stellen in diesem Gebiet gestauchte Moränen eingetragen worden. Sie bilden einen Beweis für den Druck des Landeises aus (Ost-) Nordöstlicher Richtung. Unter dem Inlandeis entstanden subglaziale Täler. Eindeutige Entwässerungsbahnen der Zichow-Golmer-Staffel und der Welsesüdrandlage konnten nicht gefunden werden. Die Schmelzwässer dieser Eisrandlagen dagegen bildeten Bändertone im Raum südlich von Günterberg-Biesenbrow.

Im Raum Wartin - Schönow - Kunow - Hohenfelde ist ebenfalls ein deutlicher Höhenzug zu erkennen; die sog. Welsenordrandlage. Sie wird als eine Art (möglich zeitgleiche) Fortsetzung der Gerswalder Staffel aufgefasst. Im Gelände gibt es folgende weitere unterstützende Beobachtungen: Die Höhenzüge zwischen Wartin und Schönow sind besser ausgebildet (d. h. höher) als zwischen Schönow und Hohenfelde, übereinstimmend mit den Beobachtungen von MARKUSE (1969) im Bereich der Uckerseen wo die westlichen Stauchungszonen besser ausgebildet und zu verfolgen sind als die östlichen (Druck vom Eisrand mehr westlich als östlich). Weiterhin wurden in eine Grube südlich von Kunow gestauchte Schichten beobachtet, welche auf eine Pressungsrichtung aus N(N)O schließen lassen. Ca. 500 m nordwestlich von Kummerow wurde am Talhang beobachtet, dass in ungefähr 32 m Höhe NHN der Geschiebemergel von Norden auf die Kiese mit leichtem Einfallen nach Norden aufgeschoben wurden. Die Schmelzwasserströmung war von Nord nach Süd und zwischen Wartin und Blumberg wurde dabei in Höhe von 50 - 60 m NHN im Randowtal eine Sanderterrasse gebildet. Vermutlich ist das Schmelzwasser in Richtung Günterberg geflossen, wo sich andermal Bändertone formen konnten. Die Talzüge des Oder- und Schönow-Tantower Tales sind schon in dieser Zeit als subglaziale Täler angelegt worden.

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